A fiber-coupled erbium-doped microsphere laser

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Abstract: We report a demonstration of an erbium-doped silicate glass microsphere laser with both pumping (at ~980nm) and the pickup of laser output (~1550nm) provided by novel angle-polished single-mode fiber coupler.

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Optical microsphere cavities, with their very high quality-factor and sub-millimeter dimensions, are attractive new building block for fiber optics and photonics. A microsphere made of laser-active material, with an efficient optical pumping scheme, can be configured as a miniature solid-state laser. Because of the small volume and high Q of whispering-gallery modes, microsphere lasers can combine very low threshold and narrow emission linewidth. Early reports demonstrated the stimulated emission in dye-doped polysterene spheres with relatively low-Q of ~10^4 and free-beam pumping/outcoupling [1]. Reports of high-Q microspheres acting as laser cavities were focused on the achievement of extremely low threshold [2] for laser operation with Nd ions. The 1.56μm lasing in Er-doped ZBLAN spheres have been reported [3] with pumping and outcoupling by means of bulky prism couplers. We present a miniature design that utilizes a novel angle-polished single-mode fiber coupler for both delivering pump power into the sphere and the pickup of laser radiation [4].

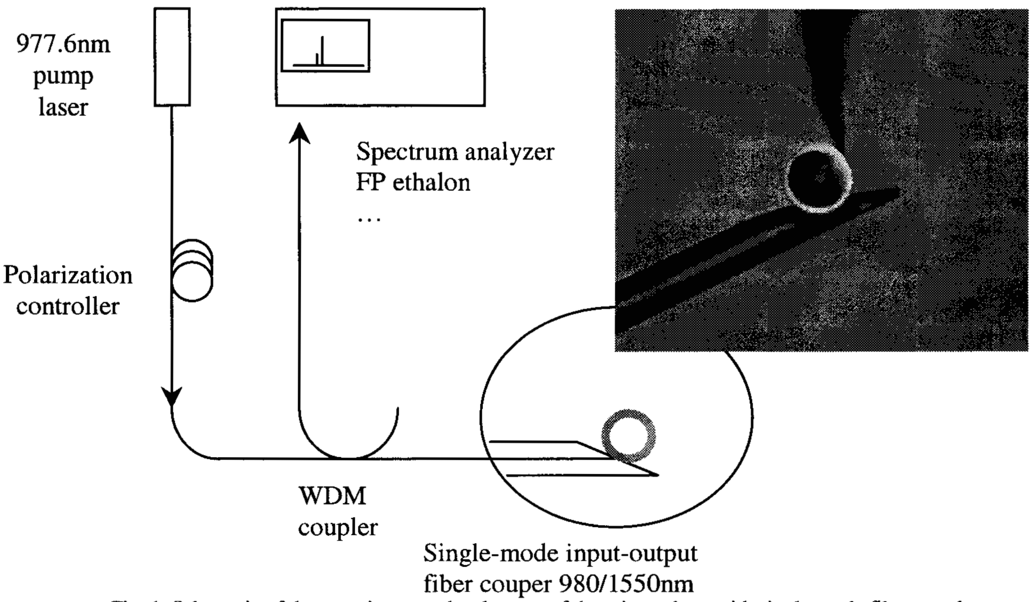

Fig. 1. Schematic of the experiment and a close-up of the microsphere with single-mode fiber coupler. The circular lasing area is visualized by upconversion-pumped fluorescence at 525/545nm

The schematic of the experiment is presented in Fig.1. The pumping radiation is provided by a commercial multimode diode laser, stabilized with an external fiber grating at the wavelength of 977.6nm. Through polarization controller and wavelength division multiplexer, the pumping radiation reaches the angle-polished fiber coupler and excites the whispering-gallery (WG) modes in the microsphere. The modes are excited in the travelling-wave regime (counterclockwise in Fig.1). The laser radiation is extracted by the fiber coupler in the direction opposite to the pump (clockwise in Fig.1), split out by the WDM coupler and sent to spectral analysis device.

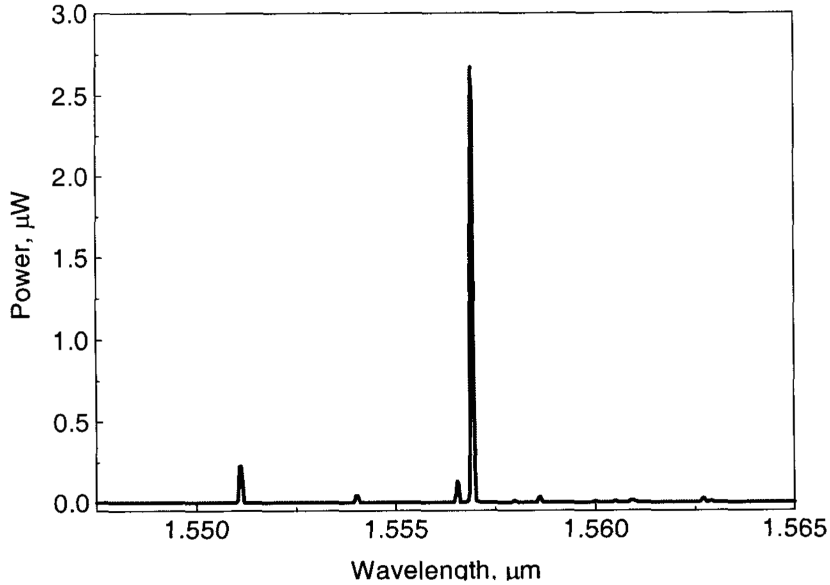

Fig.2. Typical oscillation spectrum of the fiber-coupled erbium doped microsphere laser

The spheres were produced from the 0.6mm rods of core material extracted from silicate fiber preforms (Er content 1300ppm). After homogenization of the material, a sphere of diameter about 150μm was formed by microtorch fusion [5]. Quality-factor of whispering-gallery (WG) modes at pumping wavelength (measured using Ti-sapphire laser) was found to be $Q_p = (0.5\ldots1)\ 10^6$, smaller than projected from reported material attenuation 2.8dB/m at 980nm ($Q_{Er} = 1.5\ 10^7$), apparently due to residual optical inhomogeneities. The lasing could be obtained throughout the interval between 1530nm and 1560nm. Depending on coupler alignment, spectrum of oscillation (Fig.2) contained from one to several spectral components. Single wavelength oscillation was obtained with pumping at TE, TH_{llq} modes possessing minimal volume. Analysis with FP ethalon in this regime confirmed the single-frequency oscillation. The unloaded quality-factor at the lasing wavelength, measured by means of a frequency-tuned DFB laser at 1550nm, was found to be $(3\ldots8)\ 10^6$. Self-homodyne linewidth measurements with 12km optical delay and 140MHz frequency offset yielded the emission linewidth ranging from 200kHz up to 1.5MHz – increasing with the increasing output power, similar to the reports for Er:ZBLAN spheres.

With maximum 4.5mW fed into WG mode at 980nm, laser output in the fiber was 4.1μW. Because of the excessive scattering losses, the power absorbed by the laser meduim was at least $Q_{Er} / Q_P \sim 20$ times smaller, i.e ~220μW. The lasing threshold corresponded to about 1mW coupled into the sphere (estimated ~20μW absorbed). Improved energy efficiency, as well as narrower linewidth, can be expected when higher Q, more uniform spheres are fabricated.

In conclusion, we have demonstrated a novel fiber coupled design of microsphere laser.

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